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Performance evaluation of a supply chain network

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Abstract

The supply chain network design and evaluation is a critical and difficult decision in a supply chain management. In this paper, we present a new method for evaluating the performance of a supply chain network. The main index is cost factors, which include four categories: production costs, disruption costs, co-ordination costs, and vulnerability costs. In addition, in order to describe these cost factors quantitatively, some assumptions are made. Finally, numerical analysis is adopted to illustrate its efficiency and effectiveness in searching for an optimal scheme in supply chain network design.

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1. Introduction

A supply chain is a set of facilities, supplies, customers, products and methods of controlling inventory, purchasing, and distribution [1]. In recent years, the supply chain network (SCN) design problem has been gaining importance due to increasing competitiveness introduced by the market globalization [2]. However, a general supply chain network design is a critical and difficult decision. Traditionally, supply chain network designs cover a wide range of subject areas including multiple layers, members, periods and products, and a comparative resource constraint existing between different layers. Many studies focus on location and inventory decision. But, few considered the performance of SCN such as vulnerability, stability and so on. In fact, an important component in SCN design and evaluation is the establishment of appropriated performance measures including qualitative and quantitative ones, where customer satisfaction, flexibility, and effective risk management belong to qualitative performance measures, and cost minimization, fill rate maximization and so on belong to quantitative ones. Therefore, the main objective of this research is to propose a new supply chain

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design and evaluation method, which can be used to model an actual supply chain network design process and find out an optimal scheme.

The remainder of this paper is organized as follows: Section 2 describes related work, particularly the work on supply chain network design and performance evaluation and measurement. In section 3, a method for evaluating supply chain network performance is provided. Section 4 presents methodologies for supply chain network performance modelling and evaluation and are applied to an industry case. The conclusions and future work are shown in section 5.

2. Literature review

This paper focuses on supply chain integration and its network design problem. Related literatures are analyzed in the followings.

Supply chain networks obtain raw material, supplies, manufactures, and distributes product to customers. There are several publications in the area of integrated facility location and inventory decisions. For example, *Sherif et al.* [3] developed a mixed integer linear program to integrate the location/allocation of warehouses and the routing problem such that the total costs were minimized. *Shen et al.* [4] proposed a basic integrated location inventory model that explicitly considers expected inventory costs when making facility location decisions. This model determines both facility location and demand assignment so as to minimize the total costs of location, inventory, and transportation. This basic model has been extended by other researchers. For instance, *Nagurney* [5] presented a framework for supply chain network design and redesign that allowed for the determination of the optimal levels of capacity and operational product flows associated with supply chain activities of manufacturing, storage, and distribution at minimal total cost and subject to the satisfaction of product demands. *Yao et al.* [6] considered a joint facility location- allocation and inventory problem that incorporated multiple sources of warehouses and they also formulated it as a mixed integer nonlinear programming model. *Tsao and Lu* [7] addressed an integrated facility location and inventory allocation problem considering transportation cost discount. Also, they used an approximation procedure to simplify distribution center distance calculation details and developed an algorithm to solve the aforementioned supply chain management problems using nonlinear optimization techniques.

However, the majority of these researches mentioned above suppose that the operational characteristics of the supply chain are deterministic. Unfortunately, important parameters including customer demands, prices, and resource capacities are quite uncertain. A recent study [8] found that after a company announces a supply chain disruption, its stock price can decrease significantly. This significance of disruptions has gained much more attention. *Cui et al.* [9] presented a continuum approximation model to study incapacitated fixed charge location problem in which facilities are disrupted with site-dependent probabilities. The objective is to minimize initial setup costs and expected transportation costs in normal and failure scenarios. *Lin and Wang* [10] studied the supply chain network design under supply and demand uncertainty with embedded supply chain disruption mitigation strategies, postponement with downward substitution, centralized stocking and supplier sourcing base. Also, they designed an integrated supply-side, manufacturing and demand-side operations network in such that the total expected operating cost is minimized. *Amiri* [11] considered a supply design problem with the risk of disruptions at facilities. They formulated the problem as a nonlinear integer programming model which determined the location of distribution centers and the assignments of customers to distribution centers. *Yang et al.* [12] developed a model of a general closed-loop supply chain network, which included raw material suppliers, manufactures, retailers, consumers and recovery centers. The objective of the paper was to formulate and optimize the equilibrium state of the network by using the theory of variational inequalities. *Li and Kumar* [13] reviewed the research in inter-firm network, organization co-ordination structure and performance measurement, and proposed a new method for designing supply chain scenario by considering multiple influence factors. A scenario evaluation methodology was also proposed in which supply

chain scenario performance was evaluated by considering production, system dynamics, co-ordination and vulnerability costs. *Qiang and Nagurney* [14] developed a supply chain/logistic network model for critical needs in the case of disruptions. The objective was to minimize the total network costs, which were generalized costs that might include the monetary, risk, time, and social cost. The model assumed that disruptions might have an impact on both the network link capacities as well as on the product demands. *Ji et al.* [15] presented a fuzzy programming method to design supply chain network, in which the customer demands and transportation cost were assumed to be fuzzy parameters. The authors formatted three types of models for the decision makers: expected cost optimization model, chance-constrained model and chance maximization model. In addition, the authors also used genetic algorithm to solve the proposed fuzzy modes.

3. The method for evaluating supply chain network performance

3.1. Illustration of a supply chain network

In this section, we will introduce the topology structure of supply chain network. As we all know, marketing, distribution, distribution, planning, manufacturing, and purchasing organizations along the supply chain operated independently. There organizations have their own objectives and these are often conflicting [2]. As a result, a stable and efficient supply chain network is necessary. Illustration of a supply chain network is shown in figure 1.

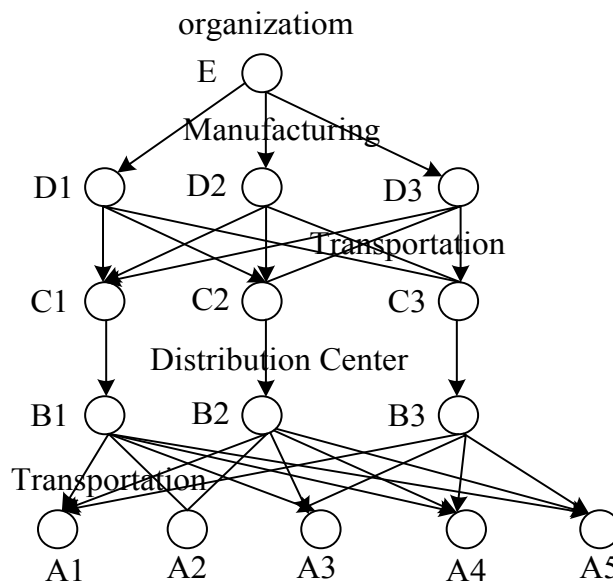


Fig. 1 Topology of supply chain network

As can be seen from figure 1, if a product can be delivered directly to the demand points from a manufacturing plant, then there would be a direct link joining the corresponding nodes. Furthermore, as depicted in figure 1, there exist manufacturing plants, distribution centres, and transportations in the supply chain network.

3.2. Supply chain network evaluation

The decision on design supply chain network depends on many factors. In this section, we select cost as the performance index for SCN evaluation. Due to including marketing, distribution, distribution, planning, manufacturing, and purchasing organizations in a supply chain network, the cost factors comprise four components: production costs, disruption costs, co-ordination costs, and vulnerability costs. Production costs refer to the operation costs when performing manufacturing, transporting and distribution activities. Traditionally, they are equal to the products processed multiplied by the unit production cost in this activity. Disruption costs refer to the costs related to the dynamics in a supply chain. It mainly include the sum of inventory and backlog costs, where the inventory cost is equal to unit product holding cost multiplied by the quality of material and the backlog one is equal to the sum of all backorders multiplied by unit product backlog price and order delay time. Co-ordination costs are the costs related to communication and decision-making, which mainly depend on the structure and quantity of messages processed. The last one, vulnerability costs, denotes the unavoidable costs of changes which are caused before the organization can adapt to a new situation. They are usually measured by recovery ability. It means that when it is easy to build an alternative link to substitute for the broken one, vulnerability cost is low and vice versa.

In order to measure these four cost factors quantitatively, some assumptions should be used:

- (1) Co-ordination costs are proportional to the number of messages.
- (2) Vulnerability costs are proportional to the costs of disrupting products due to failures of the activity processors.
- (3) Other costs caused by unexpected activities such as transportation, changes of weather are not considered.

According to these assumptions mentioned above, the four typical costs can be described as follows.

The production cost of the SCN is equal to sum generating in production process. It can be written as:

$$\sum_{k=1}^K \int_0^T (\alpha + \beta) \cdot Pu_{i-1}^k \cdot F_{i-1}^k(t) dt \quad (1)$$

Where α and β are coefficients used to represent the relationship types between organizations and F_{i-1}^k is a function of time which describes the arrival rate of order from organization for a particular product k . In addition, Pu_{i-1}^k is the unit production cost for product k in one organization.

Disruption cost is the sum of inventory and backlog costs in order to simplify the model proposed in this paper. It can be described as follows.

$$\int_0^T Invent(t)^k \cdot PM^k \cdot dt \quad (2)$$

Where $Invent(t)^k$ is the inventory at one organization at time t and PM^k is the unit product inventory cost for product k in one organization.

The co-ordination cost is the sum derived from all the product hierarchy, decentralised market and functional broker structures and so on. It can be represented as:

$$\sum_{k=1}^K \sum_{i=1}^N \int_0^T \alpha \cdot C_i \cdot F_{i-1}^k(t) \cdot dt \quad (3)$$

where C_i is the unit message processing cost between different organizations and α and F_{i-1}^k are same to the above. Note that the total co-ordination cost of all the organizations is the sum of everyone.

According to the assumptions, vulnerability costs are proportional to the cost of the change of tasks due to the failure of task processors. Therefore, the related vulnerability costs can be denoted by:

$$\int_0^T \alpha \bullet F_{i-1}^k(t) \bullet V^k \bullet \omega^k \bullet dt \quad (3)$$

where V^k is the vulnerability cost for unit product of type k in one organization and ω^k is the failure distribution of a certain organization.

From the analysis mentioned above, for the whole supply chain system, the total costs are the sum of these four different ones. In practice, related parameters should be investigated and collected in the real case so as to maintain their rationality.

4. Numerical analysis

In this section, to test the efficiency of the evaluation method proposed in this paper, a numerical analysis has been performed on a set of randomly generated supply chain network design problems described in literature [16]. The problems have been arranged in six classes as shown in table 1. Each class includes ten problems generated as follows. The demands from customers have been from a discrete uniform distribution in the range [100,150,...,300]. The values of α and β are set to 0.6 and 0.4, respectively, and other parameters such as F_{i-1}^k and Pu_{i-1}^k are defined as 10 and 100. Besides, C_j is equal to 5 and PM^k is set to 20. In addition, the order size of merchandise is set to normally distributed $N(50, 23)$. What's more, the arriving frequency of home or foreign order follows a normal distribution $N(1.2, 0.2)$.

Table 1. The set of test problems

Class	K	J	I	S
I	10	10	21	5
II	20	15	40	8
III	30	24	60	12
IV	10	8	30	4
V	20	12	50	8
VI	30	20	80	15

In order to compare the supply chain network performance under different scenarios, the total profits under these ones are introduced to analyze the benefits of considering four types of costs in the supply chain network. The results are shown in table 2. The first column marks the number of classes. The total costs under these scenarios are represented by TC_1 , TC_2 , TC_3 and TC_4 , respectively, where TC_1 denotes production cost, TC_2 is Disruption cost, TC_3 represent co-ordination cost, and TC_4 is vulnerability cost. We can see from this table that different schemes in a supply chain can correspond to different costs and with the increasing of nodes, these four classified costs are all increase. The reasons may be as follows: (1) in order to avoid lost-sales costs, fewer customers are selected to be served and it is helpful to form a stable supply-demand mechanism; (2) more co-ordinations between manufacturing plants, distribution centers, and marketing companies are needed.

Table 2 The total costs of different scenarios in supply chain network

Class	TC1	TC2	TC3	TC4
I	15746	14899	13451	24477
II	21478	20142	33412	29581

III	35256	32129	44125	39584
IV	18479	17836	48652	50217
V	26147	24786	54781	59412
VI	41756	36241	69877	71457

5. Conclusions

In this paper, we present a new method for evaluating the performance of a supply chain network. The main index is cost factors, which include four categories: production costs, disruption costs, co-ordination costs, and vulnerability costs. In addition, in order to describe these cost factors quantitatively, some assumptions are made. Finally, numerical analysis is adopted to illustrate its efficiency and effectiveness in searching for an optimal scheme in supply chain network design.

The future work may be focus on the following two aspects: (1) how to use this method to other fields need further study; (2) other influence factors such as time, customer satisfactory may also affect the decision-making of a supply chain network design. As a result, how to quantify these indexes is another direction that may be explored in future

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